Influence of Operating Parameters on Mixing and Elutriation in Fluidized Bed Pyrolysis Reactors

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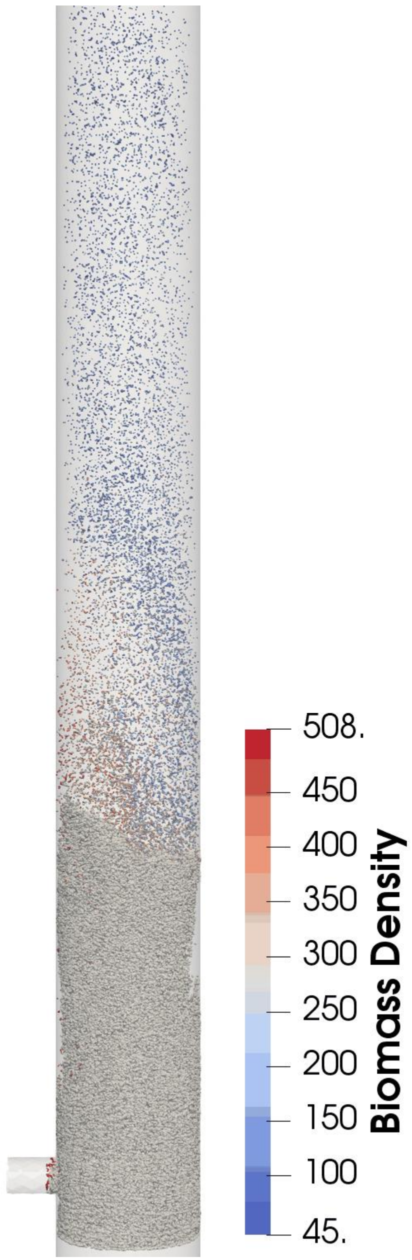
Motivation

- Efficient operation of fluidized bed pyrolysis reactors highly dependent on both mixing and residence time of biomass particles in the reactor
  - Greater mixing enhances heat transfer to biomass, increasing devolatilization rate
  - Residence time must be sufficiently long for complete devolatilization, while reducing accumulation of char
- Mixing and residence times can be tuned by varying operating parameters of reactor
  - Necessary to obtain optimal product yields
- Investigating effect of reactor tilt angle, biomass inlet angle, biomass particle size and inlet gas distribution



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Methodology

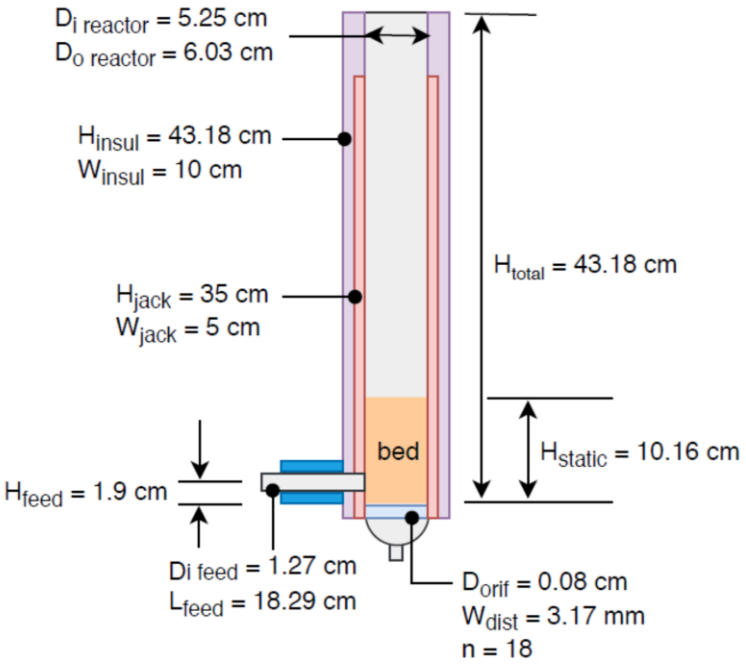
- MFiX PIC Eulerian-Lagrangian Model
  - Variable density particle model
- Gidaspow drag model

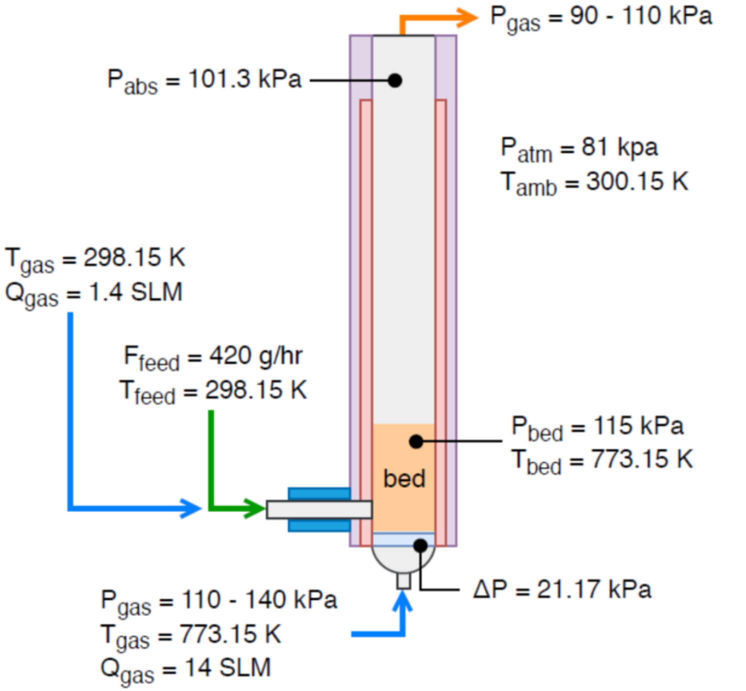
$$\beta_{gm} = \begin{cases} \dfrac{0.75 C_D \rho_g \varepsilon_m \varepsilon_g^{-1.65} \left|\mathbf{u}_g - \mathbf{u}_m\right|}{d_{pm}} & \varepsilon_g \geq 0.8 \\ \dfrac{150 \mu_g \left(1 - \varepsilon_g\right)^2}{\varepsilon_g d_{pm}^2} + \dfrac{1.75 \rho_g \varepsilon_m \left|\mathbf{u}_g - \mathbf{u}_m\right|}{d_{pm}} & \varepsilon_g < 0.8 \end{cases}$$

$$C_D = \begin{cases} 24\mathrm{Re}^{-1}\left(1 + 0.15\mathrm{Re}^{0.687}\right) & \mathrm{Re} < 1000 \\ 0.44 & \mathrm{Re} \geq 1000 \end{cases}$$

- Herning and Zipperer viscosity model

$$\mu_g = \frac{\sum\left(\mu_i x_i \sqrt{M_i}\right)}{\sum\left(x_i \sqrt{M_i}\right)}$$



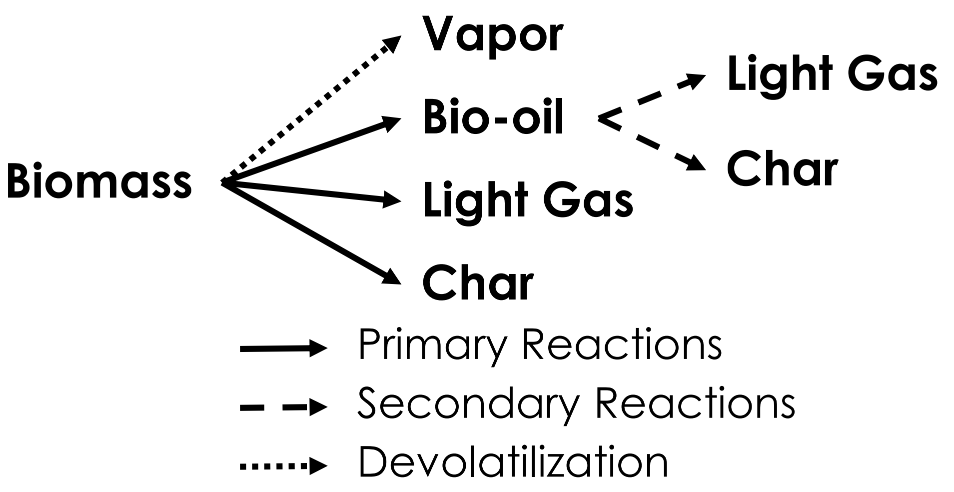


Methodology

- Modified Di Blasi kinetic scheme
  - First order Arrhenius reactions

$$k = Ae^{-E_A/RT}$$

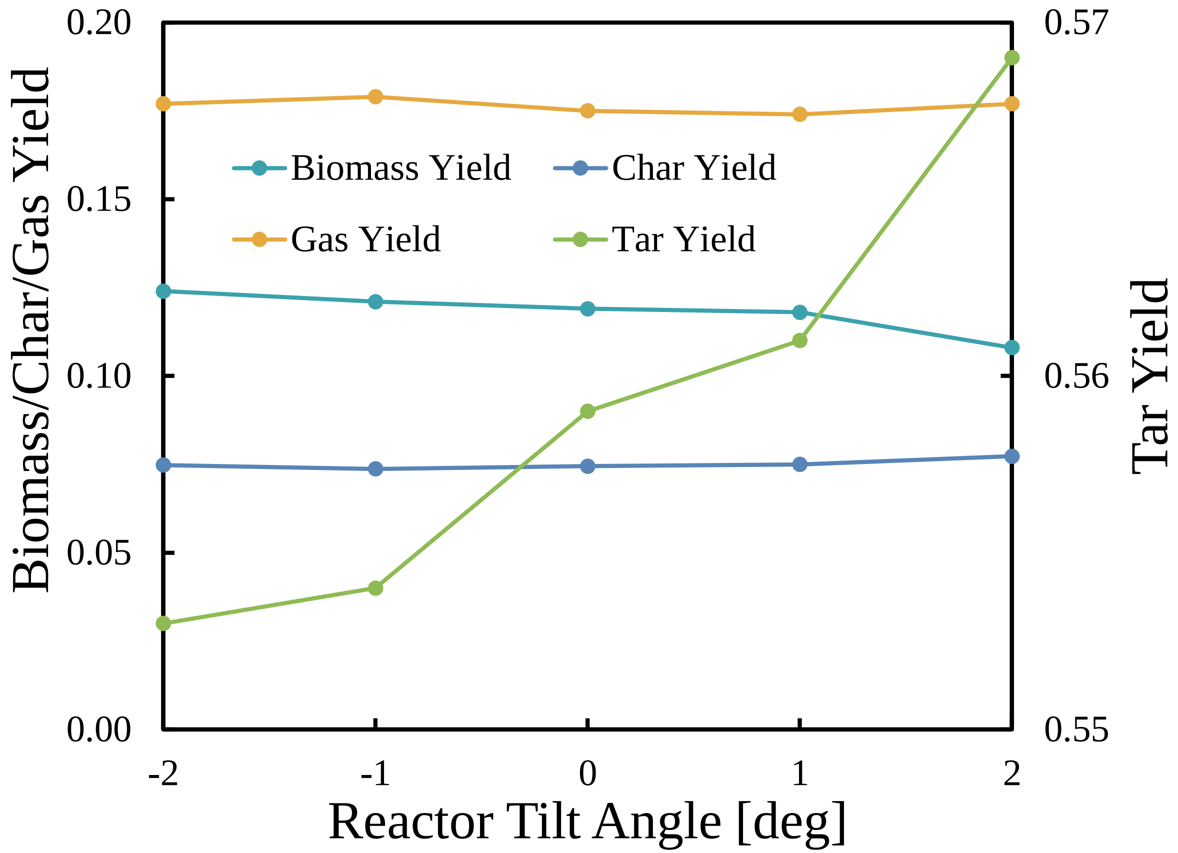
  - Additional reaction to represent moisture desorption
- Investigating influence of operating parameters on mixing, elutriation and yields
  - Biomass particle size
  - Reactor tilt
  - Angle of biomass inlet
  - Inlet gas distribution

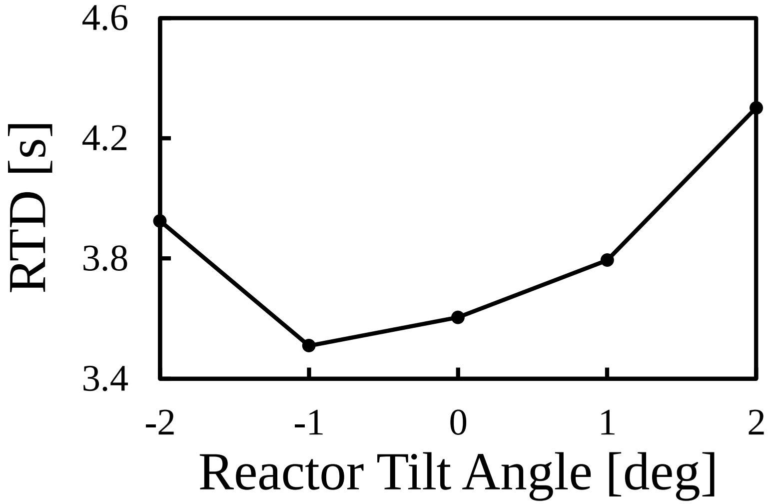


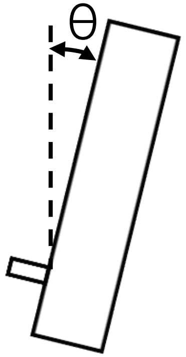
Reaction	Pre-Exponent Factor [s^{-1}]	Activation Energy [kJ/mol]	Heat of Reaction [kJ/kg]
Biomass → Vapor	5.13×10^{6}	87.9	2700
Biomass → Bio-oil	1.08×10^{10}	148	255
Biomass → Light gas	4.38×10^{9}	152.7	-20
Biomass → Char	3.75×10^{6}	111.7	-20
Bio-oil → Light Gas	1.0×10^{5}	108	-42
Bio-oil → Char	4.28×10^{6}	108	-42

Effect of Reactor Tilt

- Tilting reactor alters dispersion of biomass particles in reactor bed
  - Increases mixing, devolatilization rate
- Negligible effect on gas residence times
  - Constant fraction of tar lost through secondary reactions
- Tilting reactor produces greater bio-oil yields by increasing mixing, conversion of biomass

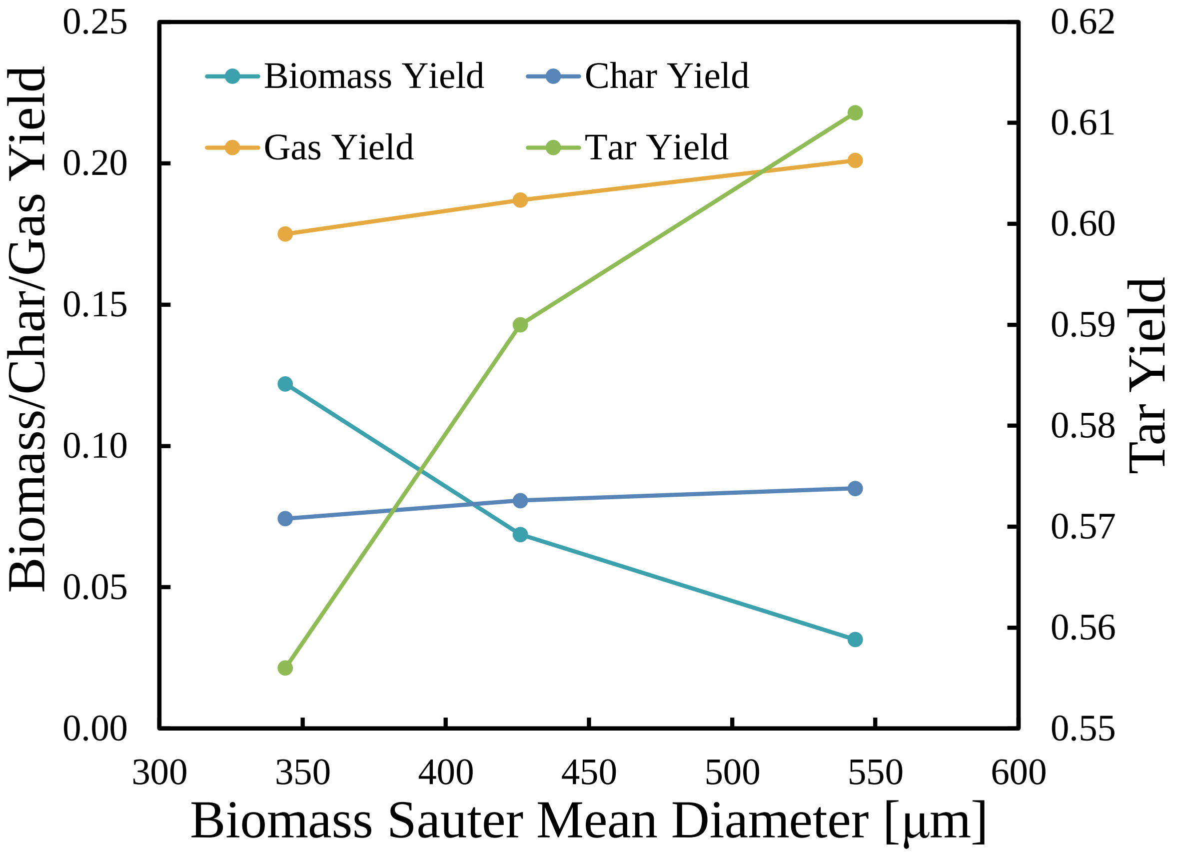


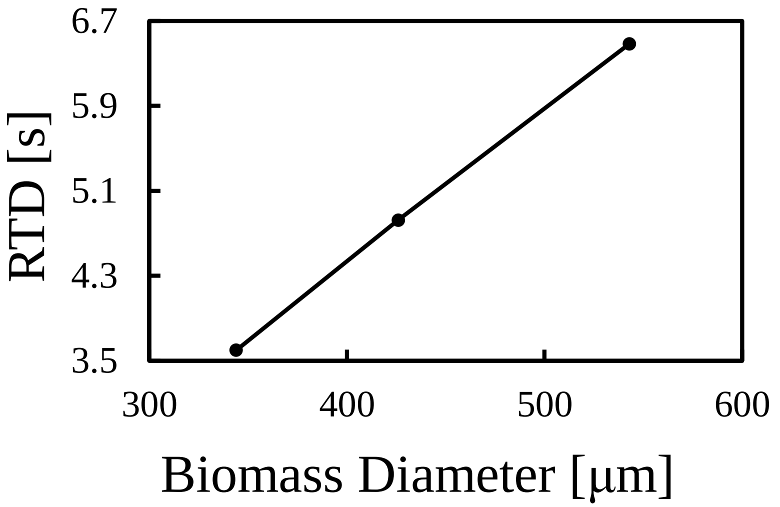




Effect of Biomass Particle Size

- Increased mass of larger biomass particles results in greater residence time
  - Almost linear relationship
- Residence time of gas remains constant as diameter increases
  - Reduces tar fraction lost to secondary reactions
- Increasing particle diameter produces greater tar yield by increasing fraction of biomass converted and reducing secondary reactions





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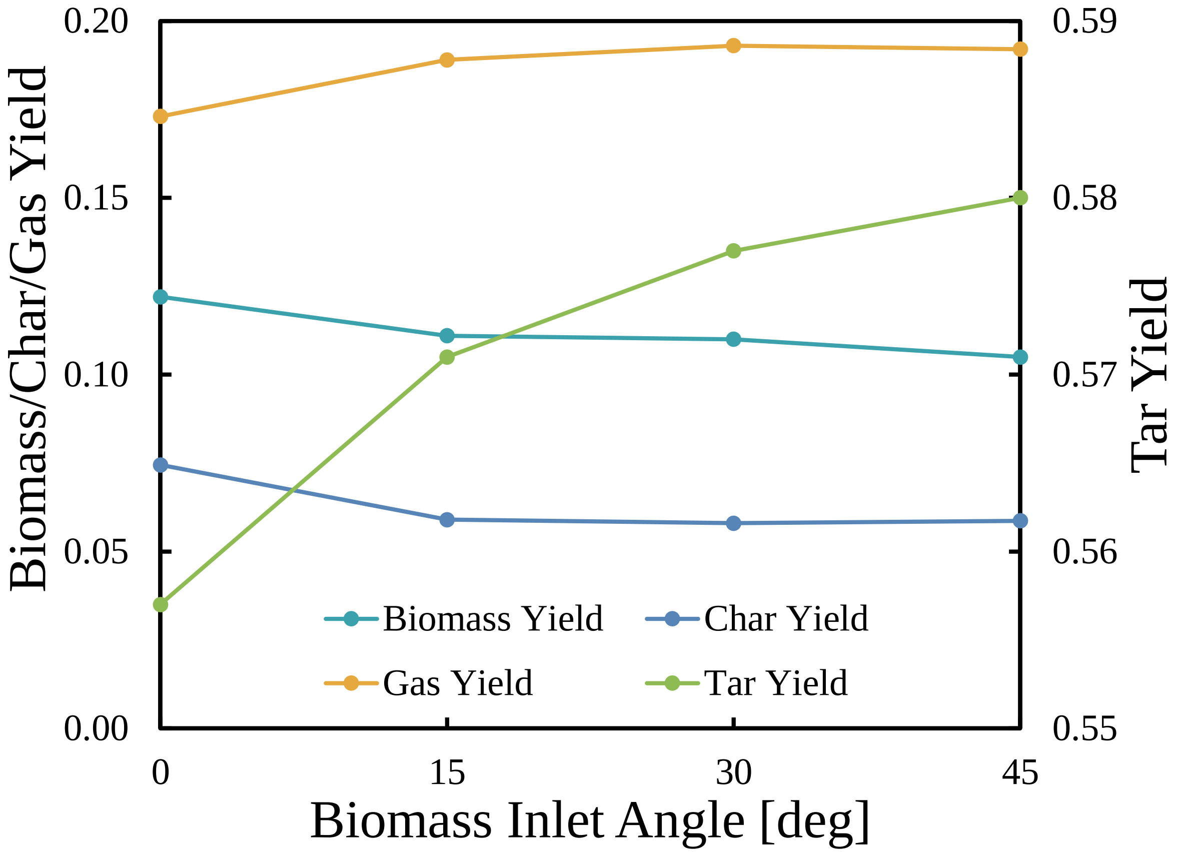
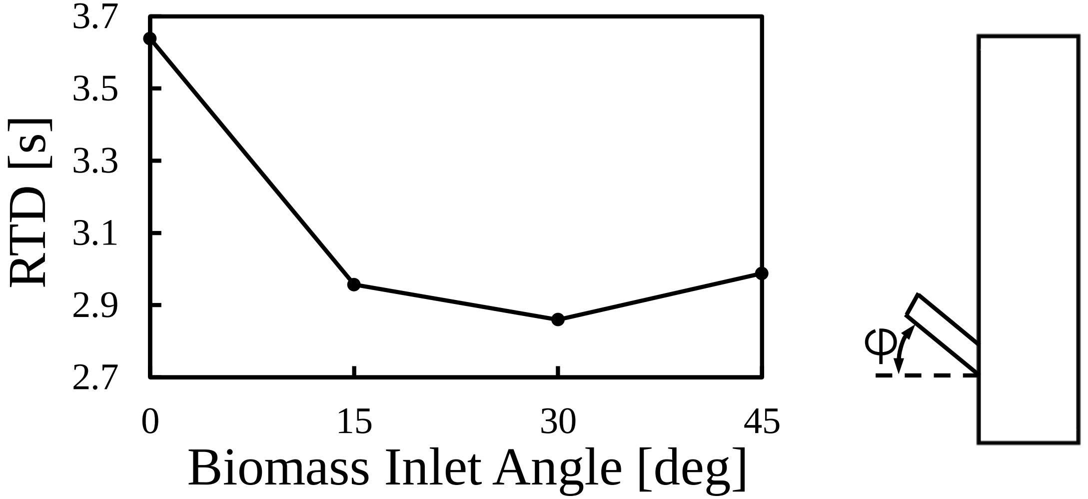
Effect of Biomass Inlet Angle

- Angling biomass inlet produces downward velocity of particles into reactor
  - Induces greater mixing of particles in bed
- Increased mixing enhances devolatilization rate, increases distance traveled by particles
- Angling biomass inlet increases conversion of biomass to tar and gas products by enhancing mixing and increasing devolatilization rate





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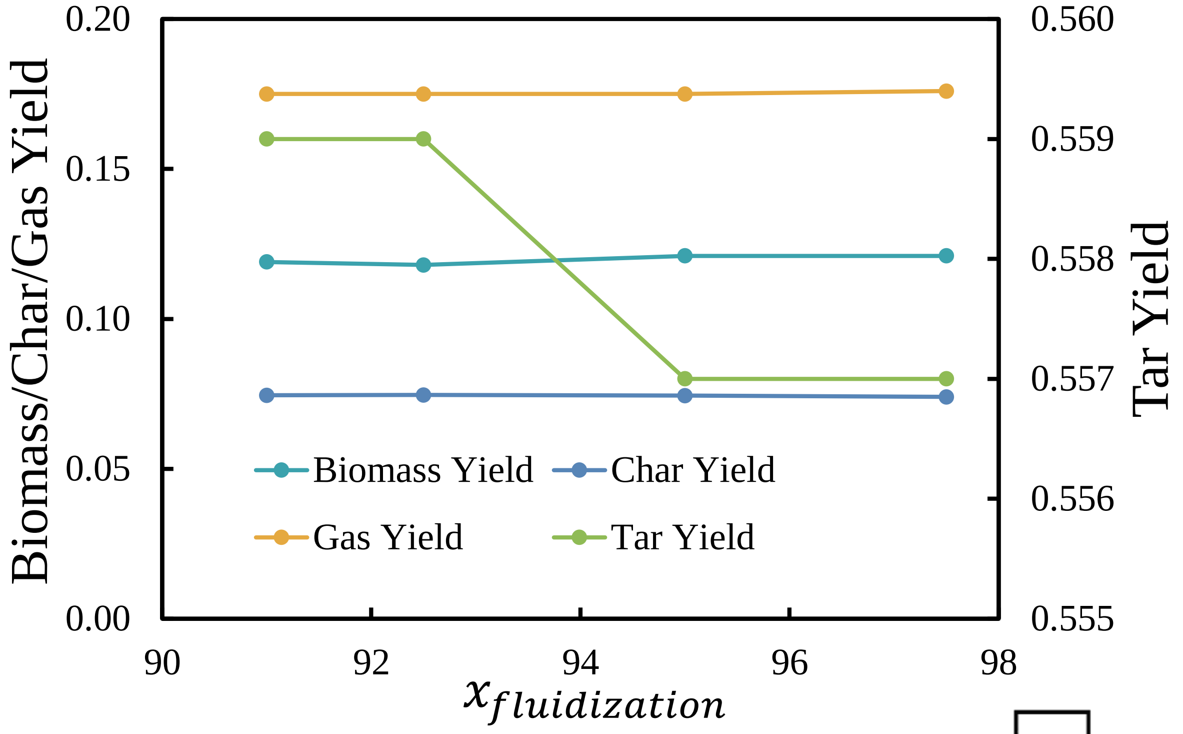
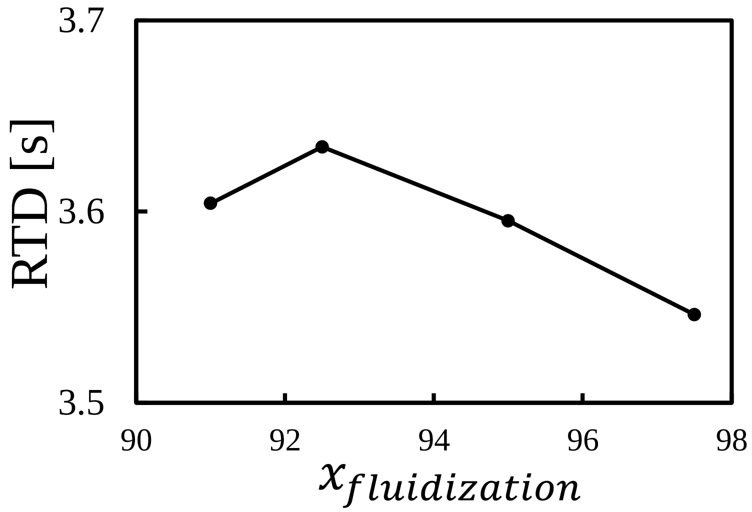
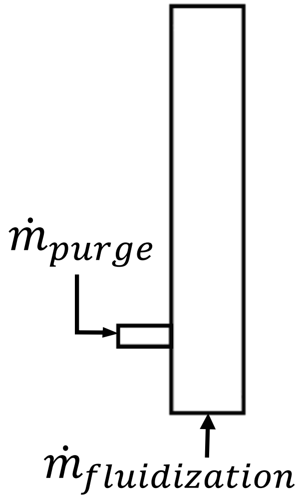
Effect of Inlet Gas Distribution

- Decreasing mass flow of purge gas reduces dispersion of biomass particles into reactor
  - Reduces mixing
- Lower mass flux of cool purge gas allows for greater devolatilization rates
- Total mass flow of gas through system kept constant
  - Constant gas residence times
- Inlet gas distribution has negligible effect on yields







$$x_{fluidization} = \frac{\dot{m}_{fluidization}}{\dot{m}_{purge} + \dot{m}_{fluidization}}$$

Summary

- Investigated influence of operating parameters on mixing and residence time of biomass particles in bubbling fluidized bed pyrolysis reactor
  - Reactor tilt, particle size, biomass inlet angle and inlet flow distribution
- Influence of reactor tilt and inlet angle on mixing effects devolatilization rates
  - Larger devolatilization rates produce higher conversion rates of biomass
- Greater residence time of larger particles allow for greater conversion of biomass
- Distribution of mass flow at inlets has negligible influence on product yields
- Constant gas residence times reduce influence of secondary reactions on tar yields